# Growing organic apples in Europe

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## 1 Introduction

### 1.1 Organic fruit production

Organic agriculture (OA) or organic farming (OF) can be defined as a sustainable holistic farming system that includes the whole food processing chain from farmer to consumer. Private organic associations (under the international umbrella organization IFOAM www.ifoam.bio) and also the legislation for OF in Europe (Council Regulation (EC) No 834/2007) cover the production and processing sector, and there is a specialized and well-labelled market segment for organic products. Four principles best define the ethical values of OA expressed by IFOAM: health, ecology, fairness and care (for more information, see http://www.ifoam.bio/en/organic-landmarks/principles-organic-agriculture). The main principle of OF systems in EC Regulation 834/2007 is specified as the appropriate design and management of biological processes based on ecological systems using natural resources that are internal to the system. Where 'off-farm' inputs are really needed, these are restricted to inputs from organic production, natural or naturally derived substances, and low-solubility mineral fertilizers. Genetically modified organisms (GMOs) and products produced from or by GMOs are incompatible with the concept of organic production.

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Organic fruit production was one of the later branches of organic cultivation in Europe. The first few pioneer fruit growers in several European regions started OF with little or no scientific support in the 1970s. They experienced losses and took risks that nowadays are difficult to imagine. The first specific research activities were started in close collaboration with local producers in the 1980s. Since then, the sector has continuously increased and now at least 10% of the fruit-growing area in several important fruit-growing regions in Europe, such as Northern Italy, Germany and Austria, is under organic cultivation. This was mainly due to innovation in the plant health care strategy, including development of appropriate equipment for tree row tillage and the introduction of new varieties with lower susceptibility to scab (*Venturia inaequalis*). In fruit-growing regions where OF is more important, specialists are now employed in the regional research stations who collaborate closely with growers. Where local institutes for OA exist (e.g. GRAB in France, FiBL in Switzerland and LBI in the Netherlands), they have established specialised working groups for fruit growing. However, there is still a strong need for research activities to create more resilient systems that provide a high number of ecosystem services. The key challenges for research can be summarized as follows:

- Development of varieties and rootstocks suited to OF systems
- Improvement of the management of soil fertility in organic fruit growing
- Improvement of the strategies for plant health care in organic fruit growing
- Improvement of the ecosystem services of organic orchards

## 1.2 The participatory and holistic approach to researching in organic apple production

OF was developed by pioneering fruit growers in close cooperation with consumers and retailers who were interested in fruit obtained through organic production. These growers made the initial steps with little research support, and experienced risks and economic failures hardly imaginable today. The first key innovations were on-farm innovations; for example, a fruit grower invented and constructed the first effective machine for tillaging rows of trees (see Fig. 1). These pioneers subsequently organized working groups and national networks of fruit growers, researchers and advisers with organic associations. One such network is the 'working net' of the German FOEKO e.V. (Kienzle et al., 2010, 2012), which also involved the coordination of the international ecofruit conferences. Organic fruit growers not only express their needs for new or improved management tools but actively engage in their development and that of their farming system and of their standards. Participatory research approaches mean a close collaboration between researchers and farmers. The combination of defined trials and on-farm tests where farmers' ideas and demands are included have led to the successful development and implementation of several measures in OF.

However, participatory approach is not limited to the collaboration of farmers and researchers. For many issues, to achieve a real impact on OF practice, the whole production chain must participate. This means that consumers, retailers, farmers and their associations and producers of inputs as fertilizers or biocontrol products must be involved in the generation of solutions.


**Figure 1** The first prototype of the equipment for successful tillage of the tree row with the pioneer fruit grower/designer. Author J. Kienzle.

# 2 Developing varieties and rootstocks suited to organic farming (OF) systems

The availability of suitable varieties and rootstocks is a key factor for the development of a more resilient fruit-growing system in OF.

*Varieties* should present a durable level of low susceptibility towards the most important diseases, pests and to abiotic damage such as frost or sunburn. Growth and fruit set should be relatively easy to regulate with the measures available in OF and the yield should be reliable and high. Fruits should be tasty, salubrious, low in allergens and with a high dietetic value ingredient content and present a good shelf-life and storage stability. Furthermore, the range of varieties should ensure the availability of organic fruit in good quality over the whole marketing period of the apples in Europe.

In the 1990s, many new varieties from breeding programmes around the world were tested and advertised to be tolerant or to carry resistance to one or more diseases. For a few promising varieties, concerted actions to introduce them into the market were started by the growers. More recently, it has become evident that these varieties did not really meet the long-term needs of sustainability for OF. Breeding techniques, based on genetic modification, are not accepted by the organic agricultural movement regardless of whether genes of the own species (*cis*-) or of other species (*trans*-) (BOELW, 2015; Eurobarometer 1991–2010) are used. Thus, special rules for organic breeding have been developed (Ristel and Sattler, 2014), and the first steps for new breeding programmes dedicated to produce varieties through OF can be observed in different countries, for example, Germany and Switzerland. These programmes particularly reflect the organic ideal of close cooperations between farmers and research stations, aiming to create quantitative resistance using a broad genetic basis. The varieties derived from these programmes are not protected in Variety Clubs but freely available for all interested organic farmers (Haug, 2014, 2015). Cooperation with interested research stations is crucial for these participatory projects and may well lead to innovative breeding programmes.

In addition to the breeding – which may produce long-term solutions – this collaboration is of high importance as many new varieties are released with little information about their susceptibility to pests and diseases in an OF system. Recently, several research stations in the EU have collaborated with organic farmers to establish special test systems under organic conditions, or at least without plant protection measures, to ensure that relevant information about newly introduced varieties that are actually on the market is available to fruit growers (Warlop et al., 2014).

The master plan for varieties suited to OF must cover all steps from breeding to testing to the introduction to the market (Haug, 2014). Some apple varieties ('Topaz', 'Santana' and 'Natyra') were introduced to food retailers and consumers by groups of growers as part of concerted actions. For such an introduction, the availability of sufficient quantity of good quality fruit of the new variety is crucial. To facilitate the marketing of small quantities of new varieties in food retailers, Weibel et al. (2004) developed a 'Flavour Group Concept' (FGC) for Switzerland. The FGC provides additional information to the buyers on the specific flavour direction of that 'unknown' apple cultivar on the display in front of them (mild to sweet, spicy–tart, predominantly tart). To further develop the FGC, in 2002, a consortium of the supermarket chain Coop-Switzerland, organic apple growers, retailers and FiBL experts joined together in a 'Variety Team'. In contrast to Variety Clubs, the focus was not a particular variety but the active creation and promotion of an attractive assortment of scab-resistant apple varieties in a well-co-ordinated and efficient way for both growers and retailers (Weibel et al., 2004). This concept is focused very much on Swiss conditions that are rather different from the market situation in the rest of Europe.

The long-term OF challenge, however, will not be limited to the breeding, testing and market introduction of a couple of suitable varieties. The high susceptibility to pests and diseases of most current commercial varieties is not only due to a genetical predisposition. Some of them, for example, 'Golden Delicious', were initially reported as having a rather low susceptibility; however, if a clonally propagated variety (which means genetically identical plants) is cultivated in large areas, it has to be expected that pathogens adapt to its specific defence mechanisms. Moreover, due to a lack of diversity in parents used in breeding programmes over the last twenty years, many of the limited number of varieties of importance in commercial fruit production are closely related, resulting in a really narrow genetic pool (Bannier, 2011).

Thus, for a truly resilient sustainable system, it will be indispensable to broaden the genetic basis of the tolerance to pathogens not only by breeding but also by increasing the number of more distantly related varieties that are cultivated in large fruit-growing areas. In this context, local varieties that are very well adapted to specific regions should also become more important.

To meet this challenge, close collaboration of researchers of different disciplines (e.g. breeders, plant protection specialists and marketing experts), fruit growers, retailers, consumers, organic associations and NGOs is of great importance to create sustainable variety concepts accepted by all marketing partners based on high genetic biodiversity and good adaptation to local conditions. In this context, biodiversity must become part of innovative quality schemes – a special challenge for participative, interdisciplinary research programmes.

In the following, the specific situation and the main challenges in the variety sector for apples are described.

Over the past 30 years, the organic fruit-growing scene was very much engaged in the introduction of new scab-resistant varieties into production. In the 1990s, fruit quality of these varieties was insufficient for a successful market introduction. The next generation of scab-resistant varieties with higher fruit quality, such as 'Topaz', 'Santana', 'Ariwa' and 'Natyra' were successfully introduced in the market with a concerted action of fruit growers' groups and marketing organizations. However, when growers reduced the applications of fungicides for scab control, other diseases became prominent. In several European regions, sooty blotch quickly advanced to become a serious problem (Weber et al., 2016). In the last couple of years, premature leaf fall from apple blotch disease (*Marssonina coronaria*) caused considerable losses in orchards with scab-resistant varieties where fungicide applications were more extensive. Moreover, all these varieties carry only single-gene resistance (*Rvi6, Vf*) against apple scab, so as a consequence, the resistance breakdown is more and more frequently observed in European orchards. The actual potential of these varieties for more resilience in the German system of OF is shown by Kienzle et al. (2016) using data from a survey on organic farms in 2014. In several German regions, approximately 50% of the area of organic apples (in total about 3300 ha) is covered by scab-resistant varieties (predominantly 'Topaz' and'Santana'). Even if the 'resistance' is overcome in all German regions, the scab-'resistant' varieties

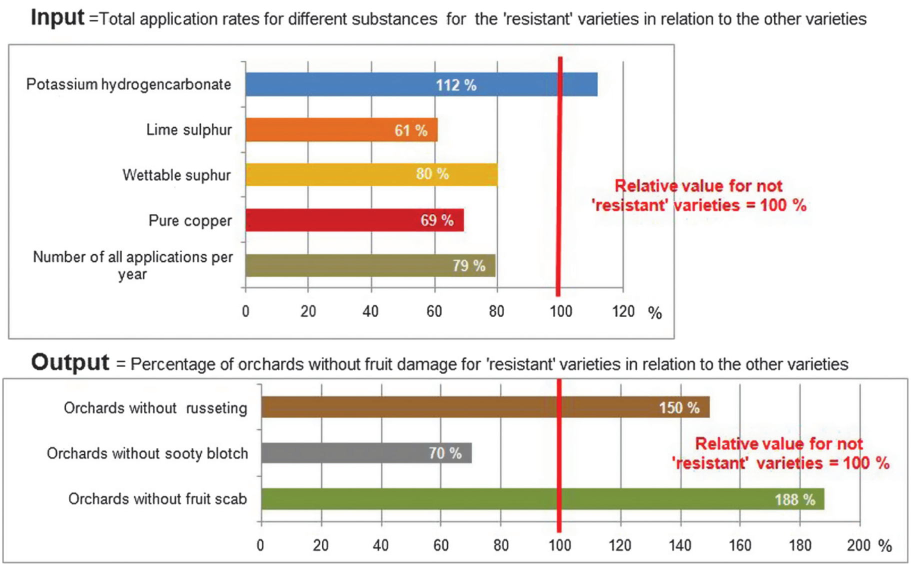


**Figure 2** Input and output of the scab-'resistant' varieties in comparison to non-'resistant' varieties in the same farms based on a survey in Germany in 2014 (Kienzle et al., 2016).

still produce a higher output (no fruit damage by scab) with a lower input (defined as the number of applications and the amounts of copper, sulphur and lime sulphur used) in comparison with the usual commercial varieties (Fig. 2). Control of sooty blotch in regions with high pressure seems to be the limiting factor. With an intelligent resistance management strategy, the use of *Vf*-'resistant' varieties still contributes to a general reduction of input and an improvement of the resilience of the growing system. Fruit growers obviously believe this, as data from the survey show the percentage of these 'scab-resistant' varieties in new plantations (from 2010 to 2014) was about 50% or more depending on the region. In Northern European countries, however, these varieties are no longer recommended by the extension services (Korsgard, oral communication, 2016). In other member states, such as Germany, these varieties are considered as a short-term strategy to reduce the inputs and increase the output. Research in these cases is focused on the development of intelligent management strategies for these varieties that preserve the resistance for a reasonable period of time.

The medium- and long-term strategies for varieties are based on two new breeding approaches:

1 Pyramiding of several scab resistances with powdery mildew (*Podosphaera leucotricha*) resistance and fire blight (*Erwinia amylovora*) tolerance (Kellerhals et al., 2016)
2 Breeding for low susceptibility to several diseases based on a quantitative tolerance on a genetical basis as broad as possible from varieties that are not closely related to large-scale commercial varieties. Avoidance of inbreeding is also an important issue (Ristel et al., 2016).

The evaluation of traditional varieties for susceptibility to different diseases as described by Kellerhals et al. (2016) or Lateur et al. (1994) is crucial for both approaches. It can broaden the toolbox for the first approach (pyramiding) as discussed by Woehner et al. (2016) for *M. coronaria* and it offers information for the second approach, in terms of the genetic control of the tolerance of potential donors (i.e. monogenic or quantitative). A close collaboration of researchers, organic farmers and the whole organic food chain in this field is one of the main future challenges for a really sustainable apple-growing system.

The first varieties with pyramided resistance can be expected to be introduced in practice in a few years (Vavra et al., 2014; Kellerhals et al., 2016). This introduction should be a solution for more resilience in the medium term. However, in a perennial crop such as apple, the pathogen goes through multiple generations in the lifetime of an orchard. Thus, it is not surprising that from the 18 resistance genes actually known, 11 have already broken down. In respect to gene-for-gene relationships, it is expected that others will follow (Patocchi and Bus, 2016; Haug, 2014). Thus, breeding for a true quantitative tolerance in combination with a higher genetic biodiversity of varieties in the main fruit-growing areas is the approach needed for sustainable long-term solutions.

The first steps towards initiatives for a complete master plan for varieties suited to OF are underway; however, activities regarding *rootstocks* are still rather limited. Initial test results for interesting new rootstocks for apple under organic cultivation are available (Pfeiffer et al., 2014, 2016; Spornberger et al., 2016; Kelderer et al., 2016). There is a great demand for rootstocks more suited to OF than the rootstocks actually in commerce.

# 3 Improving soil fertility management

Maintenance and development of soil fertility is a very important part of OF. An 'appropriate design and management of biological processes based on ecological systems using natural resources which are internal to the system' is part of the organic principles (see, http://www.ifoam.bio/en/organic-landmarks/principles-organic-agriculture). Improvement of nutrient flow on the farm and minimization of 'off-farm inputs' are very important for OA. As most fruit growers are specialized farmers without livestock, the use of organic commercial fertilizers and soil conditioners is widespread in OF. The availability of organic fertilizers is limited and this practice is not completely compatible with the organic idea of a closed nutrient flow in the farm. One solution could be: in some regions the organization of local farm clusters of specialized fruit farms and specialized livestock farms or of horse owners where the fruit farmers use the surplus of organic manure from these livestock farms for fertilization. Another solution could be the on-farm production of fertilizers. Buchleither et al. (2014) tested a dense sowing of peas as an alternative nitrogen source to commercial organic fertilizers. He concluded that the success of nitrogen fertilization with pea dense sowing is highly dependent on weather and soil conditions and, thus, fertilization with commercial nitrogen fertilizers like 'Bioilsa' pellets was simpler and more reliable. Furthermore, an early sowing date is necessary to enable an adequate period for germination, growth and mineralization after incorporation. Sufficient availability of nitrogen is only enabled at bloom of the trees if these factors are considered. The idea of producing fertilizer on farm is also discussed by Kienzle et al. (2016) within the framework of vegetation management in the alleys to improve biodiversity. Granatstein (2016) showed that cover crops other than grass in the alley can provide various functions in OF including nitrogen fixation, biomass for mulch, soil improvement and flowers to attract beneficial insects. Further research is required to elaborate such strategies into practice in different regions to ensure the availability of nitrogen when needed and to avoid mobilization in late summer.

For these reasons, fertilization strategies in OF have to always consider a combination of direct fertilization and the vegetation management both in the alley and the tree rows. Timing and modality of tillage in the tree row is especially crucial for accurate timing of nitrogen mobilization. This approach is very clearly specified by Kelderer et al. (2014) who showed the effect of different combinations of tillage and fertilization with different techniques and different application dates in Northern Italy. Kelderer et al. (2014) observed a significant increase in yield due to fertilization. In northern Europe, where soil temperatures in spring are low, the challenge for nitrogen mobilization at the right time is even higher. Weibel et al. (2014) compared different fertilizers and stated that tree performance (yield and growth) in an organic orchard system under Swiss conditions cannot be 'boosted' with organic soil N fertilizer or organic foliar N fertilizers. In each case, he concluded that organic fertilizers can hardly compensate for suboptimal soil conditions. The importance of soil sanitation before planting was highlighted. Different organic fertilizers were compared in a long-term trial in Northern Germany (Ristel et al., 2016); no significant differences in yield, fruit size or colouring between the fertilized and the control plots could be seen from the 5th until the 17th year after planting the orchard.

Some farmers do, however, increase fertilization as yields are 15–30% lower than in conventional fruit growing, a fact they partly attribute to lower fertilization levels (Weibel et al., 2014). Evaluation of the effect of fertilization should consider not only the yield but also the fruit quality and the shelf-life of the fruits. In this context, the approach of Malusa et al. (2014) to use formulations based on rhizosphere microorganisms (e.g. mycorrhizal fungi, plant growth promoter bacteria and rhizobia) seems very interesting. Effects reported can be improved plant nutrition and/or the increase of fruit quality or enhanced tolerance to biotic or abiotic stress. The formulation of inoculum with a reliable and consistent effect under field conditions is still a bottleneck for their wider use. Choice of the technology for inoculum production and for the carrier for the formulation is the key to their successful application (Malusa et al., 2014).

Exploration of locally available organic fertilizers and examination of their quality and potential for application in OF are important regional research in areas close to OF (Kelderer et al., 2008). Malusa et al. (2014) evaluated the feasibility of different organic sources available in Poland as fertilizers for OF. The use of compost of brown coal in combination with organic material increased the frequency of mycorrhizal occurrence in strawberry roots. Moeller (2014) expressed the need to use organic fertilizers in OF that have a nutrient composition close to the needs of the fruit trees, or over time, the balance of the individual nutrients could be compromised. The status quo in orchards under long-term organic cultivation should be investigated to observe the effect of different fertilization practices and to optimize strategies for the future.

Soil management in OF is not limited to the question of nutrient supply. Improvement of the soil structure, and enhancement of organic matter content and of the capacity for water retention have to be considered. For these parameters, preparation of the soil before planting is very important. One possible reason for the lower yields in OF may be that measures to reduce the replant disease are not yet fully developed for OF. Within the framework of a European project, Kelderer et al. (2016) tested different tools for mitigation of replant. The effect of a range of microbial-based preparations and composts tested on potted trees on shoot length, shoot dry weight and leaf colour of plantlets was limited (Kelderer et al., 2016). However, a combination of steaming and certain plant extracts and cover crops showed interesting results in initial field studies on young trees (Kelderer, 2016). These treatments should be tested under different climatic and soil conditions under organic cultivation, especially if new rootstocks with tolerance of replant disease can also be part of the strategy.

The increased use of permanent netting structures for hail protection and resulting inflexibility of spatial arrangement of tree rows raises the importance of intensifying research on replant disease for both conventional and organic production.

# 4 Strategies for improving plant health care: pest and disease control, regulation of crop set and tree growth

## 4.1 General aspects

The definition of integrated pest management (IPM) in the thematic strategy (EC directive 2009/128) on the sustainable use of pesticides (p. 74, Art. 2) is:

> IPM means careful consideration of all available plant protection methods and subsequent integration of appropriate measures that discourage the development of populations of harmful organisms and keep the use of plant protection products and other forms of intervention to levels that are economically and ecologically justified

> and reduce or minimise risks to human health and the environment. 'Integrated pest management' emphasises the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms.

This definition is also valid for OF. For OF, however, there is a different economic sustainability compared to IPM: OF must respect its principles to maintain its credibility. Due to these principles, it can achieve a higher price with a different level of accepted external qualities that can balance a higher risk of losses and lower yields. However, there is a limit to the feasible and maintainable price level; thus, OF must also balance the organic approach with what is economically realistic within the margins of the accepted prices, accepted qualities and feasible public support.

Biodiversity in plant health care strategies plays a central part of OF principles, including the genetic biodiversity as well as the species and structural biodiversity in the orchards. High biodiversity and a high diversity of measures within the frame of intelligent combination strategies are the backbone of resistance management in OF. Cultivation measures available to reduce the infestation of pests and diseases in practice aim to have a high resilience in the farming system. However, fruit growing is one of the few branches of OF where, in combination with these measures, the direct input of plant protection products and other substances by spray applications is common practice. Within the frame of intelligent combination strategies with the above-mentioned practice, a high efficiency is not an imperative for these substances. Efficiency of the whole management strategy is important. Many substances traditionally used in OF are 'multi-actors' with properties that allow simultaneous use for direct or indirect pathogen control, bio-stimulant and/or fertilization purposes.

OF principles restrict the use of these inputs to natural or naturally derived substances. For substances where there is an already existing exposure in natural systems, the likelihood of unpredictable risks is considerably reduced. Given our lack of complete understanding of the processes in ecosystems, this restriction is due to a precautionary and preventive approach to avoid such unpredictable risks. This holistic system approach is not part of the actual risk evaluation system for pesticides. In these systems, usually only criteria derived from the hazard criteria assessed during the currently established registration process are considered. The unpredictable risk, the probability that there are effects of newly designed substances that are not covered by these assessments, is not considered in these evaluation systems.

For OF in the future, it will be more difficult to draw the line for products that should not be included in organic standards as the number of 'ecopesticides' will increase and probably also include 'borderline cases'. It will then be important to not only consider if a substance occurs in nature but also include quantitative and qualitative (i.e. if the system of occurrence is very different from agroecosystems) aspects regarding how it occurs in nature as part of the comprehensive survey of estimation. It will be an important challenge for researchers to support the responsible organic players in suggesting indicators for this evaluation.

The natural occurrence in the ecosystem and a long experience of historical uses may be advantageous, considering the probability of the occurrence of unpredictable risks. Companies, however, are often reluctant to invest in the registration of such substances as it is nearly impossible to protect the intellectual properties and, thus, the return on investment. Furthermore, the registration of naturally occurring substances is still difficult as the process was designed initially for synthetic substances despite the fact that the special requirements of 'organic' substances are now considered in Europe. Thus, researchers must not only focus on the technical issues of the development of new or on the improvement of traditional substances for plant health care but also attend to and support registration of the substance. Unless these substances can be registered, there will be no impact on OF practice.

## 4.2 Weed control

Most OF systems use rootstocks that require weed control in the tree row during the whole life cycle of the orchard or at least during the first years of tree growth. Weed control in the row is not only important for the reduction of competition for nutrients and water, tree row management is also responsible for mobilization of nitrogen, water retention and, last but not least, control of voles and field mice.

Establishment of annual crops within the tree row gave better yields than permanent cover with grass or clover in northern Europe (Kuehn and Pedersen, 2009). Benduhn et al. (2006) tested different tillage and mulching types for OF. Mulching at first sight could appear to be very attractive for OF. In practice, however, it is expensive and work-intensive, suppression of weeds is incomplete and there are frequently serious problems with voles and field mice. A vegetation-free soil strip subject to repeated tillage does not meet the organic ideal of sustainable soil management. The Swiss sandwich system, a combination of resident vegetation and tilled strips, was developed in Switzerland (Schmid et al., 2004; Zoppolo et al., 2011) where a small strip of vegetation remains in the middle of the tree row during tillage. This method improves the structure of the nematode web in the soil, an important sustainability parameter (Zoppolo et al., 2011). The sandwich system was not implemented in OF practice in most European countries due to several practical difficulties.

Frequent tillage is usually discussed for negative effects on the soil as well as consumption of energy. Actually, depending on the regional climatic conditions, combination strategies of tillage in spring for nitrogen mobilization followed by a light cover of the tree row with the vegetation cut from the alley in combination with a new machinery that removes weed by brushing is practised in southern Germany and in Italy. The use of annual crops in summer is also in discussion.

Further research is needed to elaborate optimal strategies combining different measures that reduce energy consumption and best meet the requirements for the tree row management mentioned previously. In this context, monitoring of the various available equipment for in-row tillage in different ambient conditions is needed.

Preparation of the soil before planting is very important to determine the infestation pressure of weeds and the quality of the soil in the future. A green manure period before planting is usually advised for all crops.

## 4.3 Disease control

The strategy for a sustainable disease control in organic apples must target not only the main diseases such as scab and powdery mildew but also the minor diseases such as sooty blotch (Weber et al., 2016) or *Marssonina coronaria* that occur when fungicide applications are reduced (Bohr et al., 2016). Indirect methods are an important part of the OF strategy. As a matter of course, the choice of less susceptible varieties is the first and most crucial point. However, even if 'established' organic fruit growers in regions with a climate favourable for the major diseases usually hold a high proportion of the less susceptible varieties available, newly converted farms present the usual spectrum of more susceptible commercial varieties. For this reason, two strategies are developed: (1) sustainable long-term strategies based on less susceptible varieties and (2) short-term transition strategies based on mainstream varieties typically in use in IPM. However, there is a limit to the feasibility of these strategies depending on the region; it is usually advised that some varieties very susceptible to certain diseases (e.g. 'Golden Delicious' to scab or 'Kanzi' to fruit tree canker) should not cover a large proportion of the farm area in regions where the respective diseases are of high prevalence.

These strategies rely on the combination of several measures. Reduction of infection potential is considered highly relevant. For apple scab, strategies have been developed for the reduction of ascospore concentration before the beginning of the season by mechanical removal of leaves (Benduhn et al., 2016) and different autumnal treatments to accelerate their decomposition (Buchleither et al., 2016; Porsche et al., 2016). Korsgard (2016) tested an irrigation strategy where the orchard floor is irrigated 24 hours before forecast rain to elicit the release of ascospores, which will then not cause infections. A reduction of scab infections could be observed in some years and with some varieties. Further improvement and an intelligent combination of such measures is essential for future research.

Direct control measures in OF are predominantly based on substances of mineral origin, most common are copper, sulphur, lime sulphur and various carbonates. 'Scab stop applications' based on treatments during the period of germination of the spores were developed to reduce the number of applications (Kunz et al., 2014; Kelderer et al., 2012).

Unfortunately, although a useful control measure, copper accumulates in the soil. For this reason, the use of copper in OF is limited within the EU, for example, 6 kg/ha per year in Italy and France, and 3 kg/ha per year in Germany and Austria. In Switzerland, the limit for pome fruit is only 1.5 kg/ha per year. In several northern countries such as the Netherlands, Denmark and Sweden, no product based on copper is registered for plant protection purposes. These upper limits are rarely reached in practice. Real input data of copper in practice are available for Germany for the period 2011–13 (von Mering et al., 2016) where the medium input for organic apple orchards shifts between 1.3 and 1.59 kg pure copper per ha per year (Table 1) and for Switzerland where 0.9 kg pure copper is reported (Speiser et al., 2015) as an average input in apples in 2009–12. Strumpf et al. (2013) showed that in most German orchards the copper content of the soil is comparable in terms of magnitude with the natural copper content of the soils in the region. Copper contents in the soil that are considerably higher than the natural contents are usually a result of the high applications of copper common in conventional farming in the last century (Strumpf et al., 2013). However, a certain accumulation must be expected in the long term. Copper is also toxic to some aquatic organisms so that the drift of applications to water bodies

**Table 1** Average application rates of copper (pure copper per ha) in organic apple production in Germany in the years 2010–13 (von Mering et al., 2016)

| Year | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|
| Total area (ha) | 3400 | 3700 | 3900 | 3900 |
| Area treated with copper and analysed (ha) | 359.1 | 697.8 | 747.1 | 1.302.9 |
| Copper application rate (kg/ha) | 1.59 | 1.3 | 1.31 | 1.47 |

must also be considered. Thus, strategies must also aim to reduce the amount of copper per single application. Usually, in OF very low amounts of copper per application are used with frequent applications (splitting). Higher applications are used mainly before blossom. Research should aim to reduce the amount of copper needed during this period to reduce the risk for aquatic organisms in adjacent water bodies.

In Germany, organic associations formulated a strategy paper where four pillars for the strategy to reduce the copper amount necessary for the disease control in apples are cited (Roehrig et al., 2010): The first pillar, which is the choice of less susceptible varieties and the increase of the genetic biodiversity of the tolerance to main diseases, is discussed in Section 2. The second pillar, the improvement of the toolbox of measures to reduce the infestation potential, is already mentioned in this chapter. The third pillar is the use of forecasting models for precise timing of applications. Models such as RIMpro (Jamar et al., 2006) were developed specifically for OF, and provide information required for timing of scab 'stop applications'. Improvement of knowledge about the biology of minor pathogens such as sooty blotch and premature leaf fall (*M. coronaria*) can contribute to decision-making models that facilitate their control. The last pillar is the development of new products and/or the improvement of use of known products (Kunz et al., 2014, 2016). In this context, the potential of 'soft products' traditionally used in OF such as *Equisetum arvense* or rock powders should also be explored. No introduction or registration of suitable new products is expected in the short term; however, some reduction was achieved recently by the improvement of copper formulations (Nannen et al., 2010).

As copper as well as sulphur products present side effects of phytotoxicity on leaves and fruits under unfavourable climatic conditions, there is great interest from practitioners of alternative products or measures that respect the principles of OF. Initial results with antagonists are presented by Koehl et al. (2014) and appear promising. More research, but also more political incentives for the investment of small and medium business enterprises in this sector, is needed.

For control of storage diseases, the hot water treatments described by Trierweiler (2003) have been developed further by Maxin et al. (2014). Research is needed to adapt the method to the requirements of both small farmers and big retailers, and to improve efficacy.

Diseases of more regional importance should also be considered in the improvement of the management strategies for control. One of these is fruit canker (*Nectria galligena*) where frequent applications of calcium hydroxide in winter show good results (Heijne et al., 1998). Another is fire blight (*E. amylovora*) where a combination strategy based on antagonists and aluminium sulphate was prepared by Kunz et al. (2010).

Since prevalence of many diseases is related to rainfall in regions with high humidity, and as hail nets are becoming common practice, the idea of rain roofs seems very attractive. For apples, first trials in research stations have recently started (Bertelsen et al., 2014; Buchleither, oral communication, 2014). For some stone fruit species (e.g. sweet cherries) and for small fruit rain roofs are already rather common practice in several regions.

## 4.4 Pest control

The first and fundamental measure in the strategy for sustainable pest control in OF is the conservation of a high level of functional biodiversity in the orchard. For several pests, there is nothing available for a direct management in the toolbox of OF. Most pests, however, can be effectively controlled with the available tools for direct control in combination with measures to reduce the infestation pressure such as the occurrence of natural predators. Thus, populations of natural predators and a 'certain balance' of the arthropod fauna in the orchard has a high economic relevance that needs to be considered in decision-making for an intervention by farmers.

Several measures for the enhancement of beneficials such as the provision of refugia or overwintering places are common practice. The establishment of flowering plant strips in the alleys to enhance beneficials was started in 1986 by a farmer. Some years later, the first trials were published with weed strips that could be mulched (Kienzle and Straub, 1991), have natural vegetation and extensive mulching (Kienzle et al., 1997), and with unmulched weed strips (Wyss, 1994). However, the enhancement of these predatory arthropods failed to give complete control of key pests such as rosy apple aphid (*Dysaphis plantaginea*); flowering plants in the weed strips failed to establish in the long-term and problems with vole control occurred. For these reasons, weed strips were never introduced as a common practice (Kienzle et al., 1997). Recently, new initiatives were started with participatory and interdisciplinary cooperation of farmers and researchers with expertise in entomology, OF, vole control and plant sociology. When the first feasible management strategies of the alley with weed strips, including vole control, were drafted, a significant enhancement of the abundance of aphid predators in summer could be observed (Kienzle et al., 2014, 2016b). Fernique et al. (2016) provides an overview based on interviews with the farmers and experts involved.

Improvement of practical management strategies for enhancement of functional biodiversity, combined with measures for enhancement of different species important for nature conservation, is certainly one of the key trends in research in OF for the next years. Design of these strategies must also include disease control as some products based on sulphur can partly (e.g. predatory mites) or completely (e.g. *Trichogramma* species) reduce the population of predators sensitive to sulphur. Considerations about the genetic biodiversity of disease tolerance are also valid for susceptibility against pests. Furthermore, there are still considerable gaps to fill in the knowledge about occurrence and biology of many natural predators, even of key pests, and the understanding of the complex interactions of arthropod populations and the effects of climatic changes on their performance in the orchard is still very limited.

For some pest species, functional biodiversity can give sufficient control. The only apple aphid that requires additional direct control measures is the rosy apple aphid. The combination of extract of neem (*Azadirachta indica*) with plant oils was developed especially for OF. For woolly apple aphid (*Eriosoma lanigerum*) control, combination strategies involving various pruning methods, conventional and novel rootstocks, release and enhancement of key predators, mechanical removal (brush) and application of different plant protection products based on different oils were tested (Toups et al., 2010; Kelderer et al.,2016). As coverage with nets and even rain roofs are of increasing importance, and these measures usually enhance infestation with woolly apple aphid, research for additional biocontrol measures and information regarding the tolerance of old and new rootstocks is needed.

Apple sawfly (*Hoplocampa testudinea*) is a key pest in some European regions in OF. Direct control is successfully managed with *Quassia amara* extracts possibly in combination with neem extract (Kienzle et al., 2002, 2004, 2006). The window of application is narrow and exact timing is very important for success (Kienzle et al., 2004). Trapman (2016) developed a pre-dynamic simulation model for the biology of apple sawfly, which has been added to the RIMpro platform; however, there is still need for more biocontrol measures in the toolbox. Happe et al. (2016) reports the first interesting results for a reduction of the sawfly population by application of entomophagous nematodes in spring during hatching of adults. The incidence of the parasitoid *Lathrolestes ensator* (Brauns) was studied in the Netherlands by Zijp and Blommers (2002). In Switzerland, Babendreier (2000) observed high parasitation by *Aptesis nigrocincta*. Grav.

Codling moth (*Cydia pomonella*) is mainly controlled by a combination of mating disruption and several measures to keep the population at low levels. The most important of these measures is application of *C. pomonella* granulosis virus (CpGV), a very selective product. Since emergence of the first cases of resistance to commercial CpGV preparations (Fritsch et al., 2005), new resistance-breaking CpGV products have been developed (Jehle et al., 2016, see also 6.3).There is a clear need to develop strategies for the most effective management of virulence of CpGV. The population of diapausing larvae can be successfully reduced with application of entomophagous nematodes in autumn (Curto et al., 2008; Kienzle et al., 2008, 2010). The use of softwood stakes and bamboo sticks, which offer excellent hiding places for the diapausing larvae, should be avoided in the orchard (Kienzle et al., 2010). Application of *Trichogramma* could be valuable in late autumn when sulphur applications are terminated. Kienzle et al. (2012) tried to develop a practical method for release of this parasitoid using new species and new methods of application; however, due to the short lifespan of all *Trichogramma* species tested, this method was not introduced into practice. Even if the codling moth population is sufficiently reduced by the successful application of netting (Warlop et al., 2014) or by some newly published fructose application methods (Warlop et al., 2016), the development of additional biocontrol measures for codling moth is one of the most important future research challenges in OF.

With climate change and as fruit moves around the world, new exotic pests can appear in both conventional and organic orchards. One example is stinkbugs, which have caused a high level of damage in pear orchards and are now also observed more frequently in apple orchards. The challenge for OF will be to develop feasible control strategies for such pests that are selective enough not to compromise the existing management strategies.

Another key challenge for researchers is the improvement of the direct and indirect measures to prevent damages by voles and field mice. No baits suited to OF are available and the only effective direct control measures are traps.

## 4.5 Regulation of crop set and tree growth

The use of growth regulators is not allowed in OF. Initially, this is a challenge to the ability of the fruit grower in pruning and tree training. The balance of tree vigour/canopy size and fruit set is one of the most important parameters in the management strategies of different pests (such as aphids or leaf rollers) and diseases (scab). If mechanical pruning is introduced for reasons of labour, cost and time saving, the effects on the development of pests and diseases will have to be studied very carefully (Zimmer et al., 2016).

The regulation of crop set by hand thinning is rather expensive, thus several researchers have tried to reduce or replace this practice by mechanical and/or chemical measures suited to OF. Mechanical measures such as the rope thinner were successfully tested in several countries (Strimmer et al., 1997; Weibel et al., 2008; Sinatsch et al., 2010); their use is now common practice in some countries such as Germany.

Products for application during bloom were examined, including lime sulphur and several different carbonates that gave good results (Strimmer et al, 1997). The utilization of the effects of thinning of lime sulphur applications is widespread mainly in Southern

Europe. The effects of Vinasse (supplier Bioorga) and a product based on potassium carbonate gave interesting results in some trials (Weibel et al., 2008, 2012) whereas in other trials it was not so effective and showed some phytotoxicity (Kelderer et al., 2004).

Tree shading (Byers et al., 1985; McArtney et al., 2004; Stadler et al., 2005; Kelderer et al., 2008) is an interesting trend that is also practised in several countries to induce fruitlet drop. Another method to increase fruitlet drop is the application of transpiration inhibitors (Lardschneider et al., 2016).

The action of thinning treatments may vary depending on factors such as climatic conditions, crop growth stage, applied product(s) or product mixtures, application rates and finally crop selectivity of the applied product(s) on different apple varieties (Kelderer et al., 2008, 2012, 2014). In order to support growers in selecting the most appropriate thinning strategy for their specific farming system, it is important to investigate the influence of these different factors on the most commonly grown apple cultivars, and to develop specific application strategies for each variety and each climatic region.

# 5 Strategies for improving ecosystem services

This chapter does not aim to give a complete analysis of the ecosystem services of organic orchards and the challenges for their improvement. Instead, it will briefly highlight three important topics that are very much the focus of improvement of the OF system.

*Biodiversity* as a tool in plant health care strategies in OF offers a chance to extend these concepts into a combined management of functional biodiversity, and general issues of species biodiversity and nature conservation which offer great additional value to OF.

**Figure 3** Weed strips with flowering plants in the middle of the alleys in an organic orchard in Southern Germany. Author J. Kienzle.

**Figure 4** Single shrubs at the end of the tree rows can provide nectar and food for birds in winter. Author J. Kienzle.

There are a large number of recommendations to practice for such measures; however, implementation in practice is very low. The risks of negative side effects on the general orchard management are well known such as the increase of problems with voles and field mice or the resurgence of minor insect pests such as *Ceresa bubalus* or *Amestategia glabrata* and also diseases such as sooty blotch. Furthermore, the recommended measures often fail to reach the goals they are recommended for in terms of species and nature protection.

There is a strong demand for the development of a toolbox of measures that can be integrated successfully in the general orchard management strategy and be proved to successfully enhance functional or general biodiversity and/or the survival of certain important species. Weed strips with flowering plants in the middle of the alleys (Fig. 3) and at the border of the orchard, hedges or single scrubs at the end of tree rows (Fig. 4) and nesting aids for birds and insects form a key part of these measures.

These approaches must be tested and optimized in a participatory approach in a large number of environments before final recommendation can be made. Based upon such a toolbox of measures to enhance biodiversity, in close collaboration of OF-specialized advisers, nature and species conservation advisers with experience in OF and regional farmer groups, the full potential of organic orchards for species conservation in the agricultural landscape can be explored.

The *reduction of the carbon footprint and the energy consumption* is an important aim for the improvement of the production system. For this second topic, it would be important to have available calculation systems that allow a fast check of the effect of intended changes in the production system on carbon footprint and energy consumption.

The third goal, where there is a growing demand for more research, is the stability and the amount of *yields* from OF. Weibel et al. (2014) state that the yields in OF are about 15–30% lower than in comparable IP orchards that cannot completely be explained by losses due to pathogens or weed competition. There is a strong demand for systematic monitoring of all factors not correlated with plant protection issues which might be involved in this effect. However, the elaboration of strategies to improve yields must consider not only the effect on the amount of yield but also on fruit quality, shelf life and general plant health.

# 6 Case studies

## 6.1 Introduction of apple scab-‘resistant’ varieties in practice

In the 1990s, OF was highly interested in scab-resistant varieties. However, the varieties that were tested were not convincing in terms of fruit quality and shelf life. The situation changed with the variety ‘Topaz’ bred in 1984 by Professor Jaroslav Tupy (Strizovice, CZ), which seemed very promising. German organic fruit growers founded a society called ‘Malus bunda’ and bought the licence for ‘Topaz’. ‘Topaz’ was planted in a concerted action by many organic farmers, mainly in Germany and Austria, so that it could be introduced with sufficient volume as a new variety to retailers. However, the fast introduction also had side effects: Only when many orchards were already planted did it become evident that this variety was highly susceptible to apple collar rot (*Phytophthora cactorum*). Grafting of the variety on an interstem was recommended (Kelderer and Lardschneider, 2010), which proved to be a good cultural measure to reduce this problem. Today, ‘Topaz’ is only sold with an interstem for OF. Losses of more than 50% of the trees by apple collar rot can be seen in the first orchards that were planted. As copper applications are used to control this disease, these first ‘Topaz’ orchards are sometimes treated with more copper per year than the commercial scab-susceptible varieties (Kienzle et al., 2016a). Fruit growers in this case paid a high price for their pioneering role.

Some years later, the variety ‘Santana’, bred in the Netherlands was introduced to retailers in a similar concerted action by a group of pioneers. More professional structures exist to launch new disease-resistant varieties. The variety ‘Natyra’, also bred in the Netherlands, was selected as suitable for OF within a newly established participatory system of collaboration between researchers and organic fruit growers. A concerted action for growing sufficient quantity for a successful market introduction started some years ago (Haug, 2014).

## 6.2 Improving traditional substances suited to OF

### *Development of neem extract for the control of rosy apple aphid*

In the early 1990s, spring conditions in Europe became more and more favourable for the build-up of populations of rosy apple aphid, resulting in considerable damage in OF. As a consequence, a screening of possible substances suitable to OF for aphid control was started (Schulz et al., 1993). A combination of plant oil and neem (*A. indica*), which was known from traditional use in India for more than 1000 years, showed interesting results

(Kienzle et al., 1992). In a participatory research project with close collaboration of applied and basic researchers, a small business enterprise and farmers, a product based on neem extract for the control of rosy apple aphid in OF was developed and contemporaneously introduced into practice (Schulz et al., 1995; Kienzle et al., 1995). Hermann et al. (1995) studied the side effects on beneficial insects to ensure the optimal integration of this measure in the management strategy.

Registering this product for plant protection was a huge effort by the company involved, but since its registration, this product has been used successfully in most organic farms in Europe as an important part of the management of rosy apple aphid.

### *Inclusion of lime sulphur and carbonates in scab management strategy*

Use of lime sulphur and different carbonates in apple production dates back many years. When OF started to increase in production area and more suitable solutions for disease control were required, these substances were 'rediscovered' and their potential was explored by intensive research activities (Kelderer et al., 1997; Zemmer et al., 2002; Trapman and Drechsler-Elias, 2002; Hinze and Kunz, 2010; Kunz and Hinze, 2016; Kelderer et al., 2006; Tamm et al., 2006). 'Targeted application during infection' supported by the forecasting model RIMpro proved a successful strategy in many European countries (Jamar et al., 2010) and is nowadays common practice in most organic orchards in Europe. These strategies contribute to reduction of the input of copper but also to the reduction of the number of applications needed for disease control in OF.

## 6.3 Development and improvement of new substances suited to OF: CpGV

The CpGV was first isolated from infected larvae in Mexico and described by Tanada in 1964. All commercial products used in Europe since 2005 were based on this CpGV isolate ('Mexican strain'). Field studies showed its potential for the biocontrol of codling moth (Dickler and Huber, 1977). After an intensive collaboration of researchers and the plant protection industry, in 1988, a Swiss startup registered the first product in Europe based on CpGV: Madex. Within a very short time, CpGV proved to be successful in OF across Europe. Together with mating disruption, CpGV application is the cornerstone of codling moth control (Jehle et al., 2010) in OF.

In 2004, local codling moth populations with significantly reduced susceptibility towards CpGV-M were first observed in orchards in south-west Germany (Fritsch et al., 2005) and later in France (Sauphanor et al., 2006). Since then, further cases of resistance were reported from commercial apple orchards in Germany, France, Italy, Switzerland, the Netherlands and Austria (Asser-Kaiser et al., 2007; Schmitt et al., 2013) and an experimental orchard in the Czech Republic (Zichová et al., 2013). In a concerted action of researchers, producers and organic fruit growers, it was possible to very quickly explore the background to this resistance and to develop solutions: The resistance gene could be located on the Z-chromosome of CM, and methods for resistance monitoring were developed. Furthermore, it could be shown that alternative strains of CpGV with differing virulence to the Mexican CpGV strain could overcome the resistance (Jehle et al., 2006, 2010). New products, based on such isolates, for example, MadexPlus and MadexMAX (Andermatt Biocontrol) or Carpovirusine Evo2 (NPP-Arysta), have been developed and registered. These efforts have ensured the availability of CpGV as a tool in the strategy for codling moth control in OF. However, recently there is evidence for availability of a second type of CpGV resistance from a very few cases in Germany (Jehle et al., 2016). This resistance is targeted against a part of the available new CpGV strains. Thus, for a sustainable virulence management of CpGV, it will be important to find intelligent management strategies that use the full natural biodiversity of CpGV.

# 7 Future trends in research

The principles of OA (POA; see http://www.ifoam.bio/en/organic-landmarks/principles-organic-agriculture) provide the framework for sustainable development in OF. At first, the four principles of the POA define the sustainability concept including social, environmental and economic aspects. Organic products are 'credency' products that are based on consumers' confidence in the added values of the product. The economic success of OF relies on the acceptance of higher prices for organic products by consumers in return to these added values. Thus, there is a great economic sustainability for OF to improve the sustainability of the production system following the POA. For this reason, organic agricultural systems must continuously try to improve their orientation towards the organic principles that define the sustainability concept and are part of the organic identity. The systems approach involves the whole production chain but the basic unit is always the single farm unit. However, this farm unit is part of the whole agricultural system including consumers, retailers and also the public sector in terms of providing incentives and regulations. Often, these framework conditions are an important part of the bottlenecks that compromise approaches to improving the system. Thus, research that aims for a real practical impact must not only focus on technical issues but also consider the impact of these framework conditions and involve farmers and the appropriate players in a participatory approach.

Part of the organic identity is also that it offers opportunities for a high diversity of farm types. Therefore, researchers should not focus too much on the design of a 'best practice gold standard' for an organic orchard but should develop a toolbox of measures for more resilience in close collaboration with a high number of different organic farm types in their region. This will allow each farm unit a specific adaptation of measures for more resilience with respect to the special situation of the farm and of the farmer family. Key trends for research can be summarized as follows:

- Breeding, testing under organic conditions and introduction into the market of varieties with durable tolerance to pathogens within the framework of variety concepts that are based on high genetic diversity and therefore possibly include also a high number of varieties. The diversity of varieties should be part of the development of quality concepts that include also 'organic' standards for external fruit quality.
- Improvement of the toolbox for soil and vegetation management with the aim of enhancing the total amount of ecosystem services (e.g. yield and fruit quality, biodiversity, soil fertility and others) provided by the farm unit.
- Improvement of the existing toolbox and development of new measures and management strategies suited to OF for plant health care. The challenge in the case of product development includes not only the technical development but also the support of the registration of the substance since otherwise no impact of this research on agricultural practice is to be expected.

# 8 Where to look for further information

## 8.1 Important conferences and publications about organic fruit growing in Europe

www.ecofruit.net

'Ecofruit' is a conference that takes place each second year. It aims to bring together European researchers and consultants working on topics related to organic fruit growing. The proceedings of the 17 conferences from 1989 to 2016 are freely available for download on the homepage.

http://orgprints.org/

Organic Eprints is an international open access archive for papers and projects related to research in organic food and farming. The archive contains full-text papers in electronic form together with bibliographic information, abstracts and other metadata. It also offers information on organizations, projects and facilities in the context of OF research.

http://docplayer.pl/9595095-Lidia-sas-paszt-and-eligio-malusa.html

Book of abstracts of the international conference 'Innovative Technologies in Organic Horticultural Production', 22–24 October 2014 in Skierniewice, Poland

http://www.tfrec.wsu.edu/pages/organicfruit2012/Home

Programme and abstract book of the 2nd International Organic Fruit Research Symposium, 2012, Leavenworth, Washington, USA

http://www.ishs.org/symposium/108

Symposium on Organic Fruit Growing in Modena in 2008

## 8.2 Journals with a focus on OF

*Biological Agriculture & Horticulture*

http://www.tandfonline.com/toc/tbah20/current

*Oeko-Obstbau*

Journal in German language, specialized to organic fruit growing;
www.foeko.de/publikationen/zeitschrift-oeko-obstbau/

## 8.3 Research stations and extension services with a focus on OF

www.laimburg.it
https://www.uni-hohenheim.de/organisation/einrichtung/fg-angewandte-entomologie
www.saat-gut.org/projekte.cfm
Information about the breeding project Apfel:gut
http://www.kob-bavendorf.de
http://www.oeon.de/Versuchswesen.htm
http://www.oekoobstbau.de/F_Versuch.htm
www.fibl.ch
www.grab.fr

http://www.itab.asso.fr/itab/contacts.php
www.louisbolk.org
https://forschung.boku.ac.at/fis/suchen.person_publikationen?sprache_in=en&menue_id_in=102&id_in=253&publikation_typ_id_in=&sortierung_in=reprint
http://www.gartneriraadgivningen.dk
http://www.inhort.pl
http://www.biofruitadvies.nl
http://csanr.wsu.edu/author/granats/

## 8.4 Important organic umbrella associations and initiatives

IFOAM umbrella organization
www.ifoam.bio
http://www.ifoam-eu.org
Information regarding principles, standards and positions.

A fruit growers' specialist group exists within the frame of the IFOAM EU group. Members are researchers and farmers. Regular meetings take place within the ecofruit conferences.

www.foeko.de
German umbrella organization for fruit growers.

www.bioobst-forum.eu/de
Umbrella organization of fruit grower working groups and networks in western Europe

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